Pesticide Management for Water Quality Protection

by Melissa Landon, Jeff Jacobsen and Greg Johnson*

Maintaining good water quality is essential in Montana. The majority of Montanans (95 percent of rural residents) get their drinking water from wells. The agricultural industry depends on ground water for irrigation and stock water. Several hatcheries and many streams rely on quality ground water for healthy fish.

Pesticide residues have shown up in these water supplies. In the United States, 38 states have ground water contamination by 74 different pesticides. In a study of 229 water samples from wells throughout Montana, 25 percent of the samples had traces of one or more of seven different pesticides. The pesticide levels are below that believed to pose a threat to human health in all but one case. In some situations, greenhouse and garden plants have been damaged by contaminated well water.

Pesticides enter the environment both from point sources (identifiable sites where contaminants enter the water or soil) and from non-point sources (sites where contaminants appear from a diffused area without a clear indication of origin).

Understanding what happens to pesticides after they are applied to the land, and how they end up in the water, is a first step in pesticide management for water quality protection. Knowledge of pesticide behavior leads to sensible management practices that will protect the water resource.

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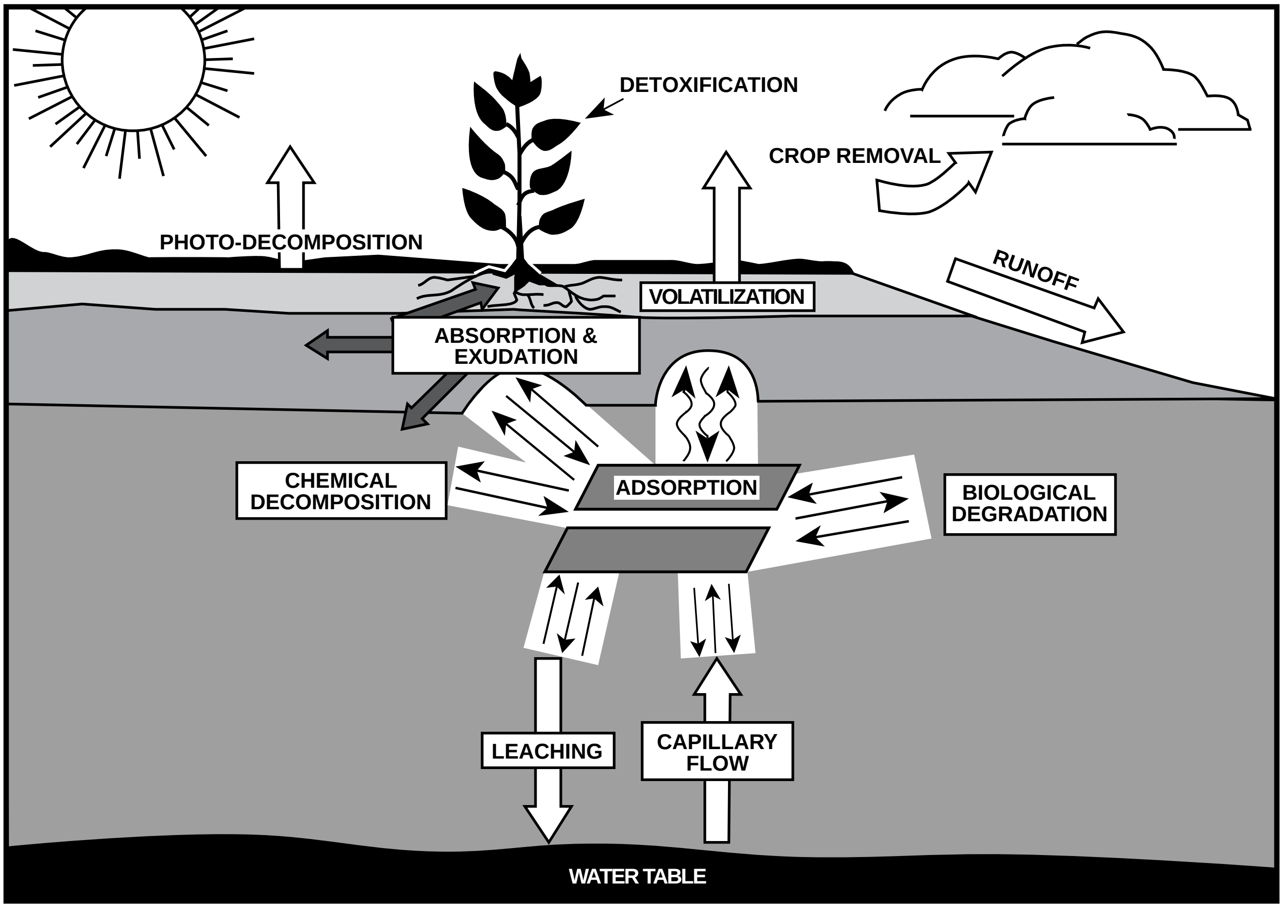

Figure 1. Fate of pesticides in the environment.

Pesticide Impact on the Environment

Pesticides have different fates after application. Some may be lost to the atmosphere by volatilization (or evaporation), particularly those designed to become gaseous following application. The gas diffuses through the soil and is not usually a threat to water. Most applied pesticides ultimately reach the soil, even when sprayed on plant surfaces. Pesticides are transported and altered by environmental forces (Figure 1). Runoff and wind erosion transport pesticides to streams, ponds and lakes. Water can also move pesticides into the soil. Here, pesticides can be taken up by plants and removed, broken down by chemical reactions or remain in the soil.

The water contamination potential from pesticides depends on:

1) the quantity of pesticide present
2) its mobility
3) the quantity of available water driving the pesticide into the soil profile or across the soil as runoff.

The fate of a pesticide is dependent on many factors including:

- pesticide properties
- soil properties
- site characteristics
- management practices

Pesticide properties

Pesticides have many different properties that affect their behavior in the environment. They are grouped or classified according to chemical structure and function (Table 1). Those with similar structures behave similarly, but may differ in their level of toxicity.

Solubility

A pesticide's solubility in water has a great impact on leaching potential and environmental fate. Oil-soluble pesticides tend to be insoluble in water. As the water solubility of a pesticide increases, there is a greater likelihood it will be leached through the soil to ground water or runoff into surface water. In general, pesticides with water solubilities of greater than 30 parts per million have an incresed tendency to leach.

Adhesion

Pesticide molecules often adhere to soil particles. Water-soluble pesticide molecules adhere to soil organic matter and clay. Oil-soluble pesticides adhere to organic matter. When pesticide molecules adhere to soil particles, they are removed from the soil water and will not leach as readily (Table 2). By remaining longer in the root zone, they degrade to a greater extent.

Adhesion varies between pesticides and affects pesticide activity and degradation in the soil. If the pesticide is tightly adhering to organic matter, microorganisms may not be able to break it down, and the pesticide will persist in the soil. Several factors affect adhesion. Soils high in organic matter hold pesticides easily as organic matter has many binding sites for both water- and oil-soluble pesticides. Similarly, soils with high clay content have increased surface area and more binding sites for water-soluble pesticides. Pesticide adhesion decreases as soil moisture or tem-

Table 1. Classification of pesticide by function and chemical structure.

Functional Class*	Chemical Category
Fungicides	Benzimidazols
	Carbamates
	Chlorinated hydrocarbons
	Phthalimides
	Traizines
Herbicides	Carbamates
	Phenoxies
	Triazines
	Uracils
	Ureas
Insecticides	Carbamates
	Chlorinated hydrocarbons
	Organophosphates
	Pyrethroids
Nematicides	Brominated alkanes
	Carbamates
	Chlorinated alkanes
Rodenticides	Coumarin
	Indandione

** Others include piscicides, avicides, acaricides, algicides, antiseptics, arboricides, bactericides, limacides, and zoocides.*

Table 2. Effect of soil and pesticide characteristics on adsorption and solubility.

Soil Characteristic*	Adsorption	Solubility
↑ organic matter	↑	↑
↑ clay	↑	
↑ soil moisture	↓	
↑ pH	↓	
↑ temperature	↓	
↑ cation exchange capacity	↑	
↑ dissolved salt		↓
Pesticide Characteristic	**Adsorption**	**Solubility**
↑ oxygen in chemical formula		↑
↑ adsorption		↓

* ↑ increase ↓ decrease

perature increase. A pesticide that is tightly bound to soil particles will not move with water through the soil, but may move off-site with soil sediments. At any time, environmental conditions (e.g., water content, salts, aeration) may change, allowing the pesticide to be released from soil particles. If not degraded upon release, it may remain an active pesticide.

Once a pesticide enters a soil, a portion adheres to soil particles and some remains in solution in the soil water. Scientists use the "partition coefficient" to measure pesticide adhesion. It is the ratio between the pesticide concentration that is adhering to soil particles and the pesticide concentration in solution. Each pesticide behaves differently in different soil. In order to evaluate the behavior of a pesticide at a specific site, we calculate the organic carbon partition coefficient or K_{oc}, which is a measure of mobility. Organic carbon content of a site (estimated to be 50 percent of the organic matter content) is used in the calculation:

$$K_{oc} = \frac{\text{partition coefficient}}{\text{percent organic carbon content in soil}}$$

The larger the K_{oc}, the more strongly the pesticide attaches to soil particles and organic matter. The smaller the K_{oc} value, the greater the pesticide concentration in water. Therefore, pesticides with smaller K_{oc} values are more likely to leach (Table 3).

Degradation

Pesticides are composed of molecules that can be broken down in the environment by degradation processes. The first step of degradation breaks a pesticide molecule into two or more different particles. Many reactions are required to completely degrade a pesticide. If complete degradation occurs, only water, carbon dioxide and inorganic (containing no carbon) components remain. Degradation of a pesticide does not, however, mean that toxicity is eliminated. In some cases, a product of breakdown may be more toxic than the original active ingredient.

Once a pesticide is degraded, it is no longer available for pest control, and its environmental impact is altered. Therefore, it is important to be aware of the degradation rate. Warmer soil temperatures will generally speed degradation, while cool temperatures retard pesticide breakdown.

- Microbial degradation is the breakdown of pesticides by microorganisms (fungi, bacteria, etc.). Microbial degradation rate is also affected by those conditions that impact living organisms: moisture, oxygen, pH (the measure of acidity or alkalinity), organic matter, soil fertility and clay content. Plant cover, pesticide concentration and chemical structure also influence degradation.
- Chemical degradation occurs due to chemical reactions not involving organisms. The rate and type of chemical reaction depend on temperature, soil moisture, soil and pesticide pH, soil adhesion and pesticide properties. The most common chemical degradation process is hydrolysis (a reaction with water).
- Photodegradation reactions break down pesticides by exposure to light. Sunlight can destroy pesticides on foliage, on the soil surface and in the air. The presence of water enhances this process. Photo-

Table 3. Relative Persistence and Mobility of Pesticides in Soils (McBride, 1988).

Herbicide	Persistence[a]	Mobility[b]
Aciflurofen (Blazer, Tackle)	M	M
Alachlor (Lasso)	L	M
Amitrole (Amitrole T, Cytrol)	L	M
Atrazine (several trade names)	H (high pH)	H
Barban (Carbyne)	L	L
Bentazon (Basagran)	L	H
Bromacil (Hyvar)	M	L
Bromoxynil (Brominal ME4, Butril)	L	M
Butylate (Sutan, Genate)	L	L
Chloramben (Amiben)	L	H
Chlorpropham (Sprout Nip)	M	M
Chlorsulfuron (Glean)	H	H
Clomazone (Command)	M	M
Clopyralid (Lontrel, Curtail)	M	H
Cyanazine (Bladex)	L	M
Cycloate (Ro-Neet)	L	M
Dalapon (Dowpon)	L	H
Desmedipham (Betanex)	L	L
Diallate (Avadex)	M	L
Dicamba (Banvel)	L	H
Diclofop (Hoelon)	L	L
Diethatyl (Antor)	L	M
Difenzoquat (Avenge)	M	L
Endothal (several trade names)	L	M
EPTC (Eptam, Eradicane)	L	M
Ethalifuralin (Sonalan)	M	L
Ethofumesate (Nortron)	M	L
Fenoxaprop (Whip, Acclaim)	L	L
Fluzifop-P (Fusilade 2000)	M	L
Glyphosate (Roundup)	M	L
Imazamethabenz-methyl (Assert)	M	M
MCPA (several trade names)	M	M
Metolachlor (Dual)	M	L
Metribuzin (Sencor, Lexone)	M	H
Metsulfuron (Ally)	H (high pH)	H
Paraquat (Glamoxone, Super, Cyclone)	H	L
Pendimethalin (Prowl)	M	L
Phenmedipham (Betamix)	L	L
Picloram (Tordon)	H	H
Propanil (Stampede)	L	L
Pyrazon (Pyramin)	L	M
Sethoxydim (Poast)	L	L
Simazine (Princep)	H	H
Thiameturon (Harmony)	L	M
Triallate (Far-Go)	M	L
Triclopyr (Garlon)	M	M
Tridiphane (Tandem)	L	L
Trifluralin (Treflan)	M	L
Vernolate (Surpass)	M	L
2-4,D (several trade names)	L	H
2-4,DB (Butyrac, Butoxone)	L	H

Insecticide	Persistence[a]	Mobility[b]
Acephate (Orthene)	M	H
Aldicarb (Temik)	M	H
Azinphos-methyl (Guthion)	L	L
Carbofuran (Furadan)	L	H
Chlorpyrifos (Lorsban)	M	L
Diazinon	M	M
Dimethoate (Cygon, De-Fend)	L	M
Disulfoton (Di-Syston)	L	L
Endosulfan (Thiodan)	L	L
Esfenvalverate (Asana)	M	L
Ethylparathion	L	L
Fonofos (Dyfonate)	M	M
Malathion (Cythion)	L	L
Methamidophos (Monitor)	L	H
Methomyl (Lannate, Nudrin)	L	M
Methyl parathion (Penncap-M)	L	L
Methidathion (Supracide)	L	M
Permethrin (Ambush, Pounce)	L	L
Phorate (Thimet)	L	L
Pydrin	M	L
Terbufos (Counter)	L	L
Tralomethrin (Scout)	M	L
Trichlorfon (Dylox)	L	H

[a] *H = High (half-life >100 days); M = medium (half-life >30, <100 days); L = Low (half-life ≤30 days)*

[b] *H = High (Partition Coefficient ≤ 30) M = Medium (Partition Coefficient >30, <300) L = Low (Partition Coefficient ≥ 300)*

Table 3 (continued). Relative Persistence and Mobility of Pesticides in Soils (McBride, 1988).		
Fungicide	**Persistence**[a]	**Mobility**[b]
Benomyl (Benlate, Terson 1991)	H	H
Chlorothalonil (Bravo, Daconil)	M	L
Copper hydroxide (Champion, Kocide)	H	L
Maneb (several trade names)	M	L
Mancozeb (Dithane M-45, Manzate 200, Penncozeb)	L	L
Metalaxyl (Ridomil, Subdue)	M	H
Propiconazole (Banner, Tilt)	H	M
Sulfur (several trade names)	H	L
Thiabenzadole (Mertect)	M	L
Thiophanate methyl (Topsin M)	M	L
Tridimefon (Bayleton)	H	M
Triphenyltin hydroxide (Super Tin)	H	L

[a]*H = High (half-life >100 days); M = medium (half-life >30, <100 days); L = Low (half-life ≤30 days)*

[b]*H = High (Partition Coefficient ≤ 30) M = Medium (Partition Coefficient >30, <300) L = Low (Partition Coefficient ≥ 300)*

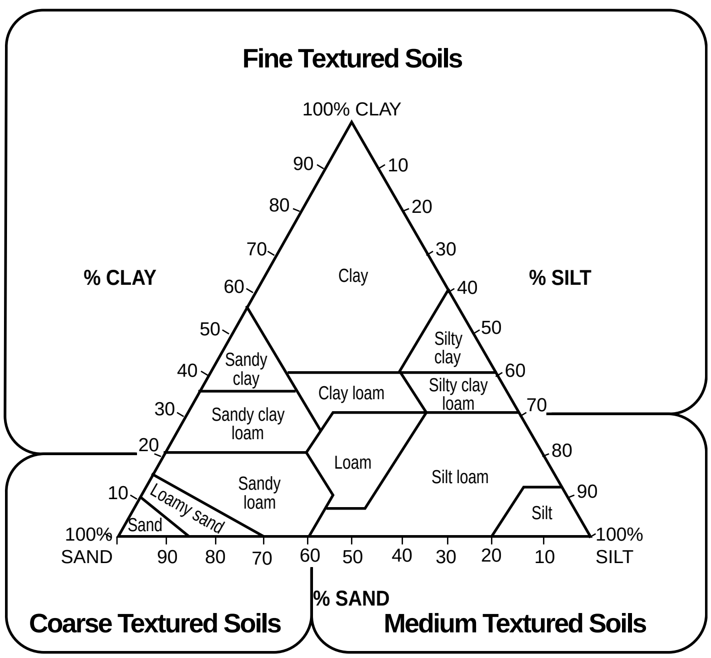

Figure 2. Soil textural triangle.

degradation is affected by the sunlight intensity, soil properties and pesticide properties and application method. Incorporation of the pesticide into the soil during or immediately after application will decrease photodegradation, but leaching likelihood may increase. Pesticides exposed to sunlight are more susceptible to further degradation by other chemical and microbial processes.

Persistence

Some pesticides are more resistant to degradation than others. The resistance can be measured by the time it takes for half of the original amount of a pesticide active ingredient (by weight) to be degraded (half-life). Half-life values are determined under laboratory conditions and are useful only as a reference point; they will vary with soil and climatic characteristics (Table 3). Generally, pesticides with half-lives of more than 30 days have the greatest potential for leaching. This potential is increased if the pesticide is highly soluble and has low adhesive strength.

Soil Properties

Soil conditions at areas where pesticides are applied affect the potential for leaching or runoff. Sandy soils (Figure 2) are coarse and porous and allow faster water percolation. With fewer particles in a given volume of soil, there is less surface area and therefore less opportunity for pesticide adhesion. Sandy soils also tend to contain smaller microbe populations. Finer-textured soils contain more surface area for pesticide adhesion and more clay and organic matter and thus, more microbes. Other variable conditions such as urface crusting and soil compaction decrease leaching, and promote runoff with a higher pesticide concentration.

Pores are often created in soil by root channels or animal tunnels. Large cracks form by freezing and thawing or by surface drying in clay soils. These pores and cracks may be several feet long and result in rapid downward water and pesticide movement through soils. Even when pesticide properties and site conditions are not normally conducive to leaching, rainfall or irrigation flowing through pores and cracks may promote pesticide leaching. The permeability of the soil ought to be considered when applying pesticides.

Soil organic matter lowers the ability of pesticides to move, decreasing pollution danger. Organic matter with its many adhesion sites delays pesticide leaching below the root zone, allowing microbes more time for degradation.

More pesticide is lost from moist soil than dry soils. Moist soils have less ability to absorb water and runoff begins earlier. The highest pesticide loss from a treated area occurs during the first runoff.

When a pesticide leaches into the vadose zone (below the root zone and above the water table), degradation and volatilization processes are reduced and ground water contamination potential is increased. In this zone, soil temperature and oxygen levels drop, sunlight penetration is drastically reduced, microbial activity decreases and soil organic carbon content diminishes. As a result, many pesticides are more persistent and mobile once they move below the root zone.

Although pesticides continue to break down in ground water, degradation is generally much slower than in the surface layer of soil and is dominated by chemical/physical processes. The relatively constant temperature of deeper ground water allows a constant, slow rate of breakdown. Coarse soils that allow water to pass through easily may also allow oxygen and bacteria to pass through to shallow ground water where slow microbial breakdown can occur when soils are not frozen.

Site Characteristics

Site characteristics strongly influence the pesticide contamination potential of water. Depth to ground water, underlying geology and permeability of the geologic layers must be considered when assessing a site's potential for water contamination by pesticides. Soil depth affects the amount of filtration and degradation. Distance to ground water varies with the seasons—it's usually least in the spring and greatest in late summer. If the geologic materials above the aquifer are very coarse (sand and gravel deposits or highly fractured bedrock), water and dissolved pesticides may percolate downward to ground water more readily than in less permeable layers (clay or solid rock) that inhibit water movement.

Site characteristics particularly important for surface water contamination include distance to surface water bodies, the presence or absence of untreated buffer zones, crop residue and the type and amount of vegetative cover. Some site conditions influence the potential to contaminate both ground water and surface water. The movement of water and pesticides through the soil will be greater on level or concave slopes, while increasing slope may decrease infiltration, increasing runoff and soil erosion.

Rainfall and irrigation influence the severity of pesticide runoff into surface waters. Heavy or sustained rain or over-irrigation can lead to accumulation of excess surface water and to pesticide runoff. The longer the period after application before irrigation or rainfall, the more degradation will take place, and the less pesticide will run off. Surface runoff is slower to develop on sandy soils, and so the initial pesticide concentrations in runoff are reduced. On finer soils with more clay and lower infiltration rates, water contamination potential increases due to more rapid water runoff.

Management Practices

Pesticide application practices influence the water contamination potential. Water contamination risk can be vastly reduced by carefully selecting the pesticide, rate, timing, application method and placement, and by following safety precautions.

Estimating Pesticide Loss and Potential for Contamination of Water Resources

Many processes affect pesticides in soil and water. The fate of an applied pesticide and its potential to contaminate water sources depend largely on the persistence, solubility and mobility of the pesticide in the environment.

The contamination potential of a particular pesticide in the environment is assessed by evaluating persistence (half-life) and mobility (K_{oc}) (Table 3). In terms of water quality, pesticides with intermediate K_{oc} values and short half-lives may be considered "safest." They are not readily leached and degrade fairly rapidly. For example, a pesticide with a high K_{oc} value (highly mobile) and long half-life (persistent) poses a considerable threat to ground water through leaching. A nonvolatile pesticide with high persistence and low mobility (low K_{oc}) is likely

Table 4. Evaluating the Potential Risk of Contamination.

Pesticide				Contamination Risk	
Persistence	**Mobility**	**Pathway of Loss**	**Water Source Affected**	**Normal Conditions**	**Saturated Conditions**
		Leaching	Ground	High	Very High
High	Low	Runoff	Surface	Low	Moderate-High
		Leaching	Ground	Moderate	Moderate-High
Low	Low	Runoff	Surface	Low	Moderate
		Leaching	Ground	Low	Moderate
High	High	Runoff	Surface	Moderate	High
		Leaching	Ground	Low	Low
Low	High	Runoff	Surface	Low	Moderate

to remain on or near the soil surface, increasing the chance of being carried to a lake or stream in sediment runoff. Without excessive water, pesticides with short half-lives remain in the biologically active root zone and degrade rapidly (Table 4).

A qualitative evaluation integrates pesticide, soil and site characteristics. The risk for contamination increases as more of the following characteristics are present.

Contributors to Greatest Ground Water Vulnerability

Pesticide characteristics

- High persistence
- High solubility
- Low soil adhesion
- Slow degradation

Soil characteristics

- High permeability
- Low organic matter content
- Presence of many large pores
- Sandy, gravelly texture
- Wet soil

Site characteristics

- Abandoned wells nearby
- Heavy rainfall or excessive irrigation
- Permeable geologic layers
- Shallow depth to aquifer

Applicator practices

- Improper storage, handling, or disposal
- Incorporation, injection methods
- Overly high application rate
- Spills

Contributors to Greatest Surface Water Vulnerability

Pesticide characteristics

- High adhesion (transport via sediment loss)
- High persistence
- Low soil adhesion and high solubility (transport via runoff)
- Slow degradation

Soil characteristics

- Erosion
- Fine, clay texture
- Low permeability
- Surface crusting and compaction
- Water-saturated soil

Site characteristics

- Absence of crop residue
- Heavy rainfall or excessive irrigation
- Increase in slope
- Lack of untreated buffer zones
- Short distance to surface water
- Short time between application and rain/irrigation/runoff

Applicator practices

- High application rate
- Improper storage, handling, use, or disposal
- Spills
- Spray drift or vapor movement

The Montana Department of Agriculture has developed an on-farm scoring system to evaluate aquifer vulnerability to pesticide contamination. The Relative Aquifer Vulnerability Evaluation (RAVE), consists of a score card to integrate nine factors into a relative numeric value. Comparing the value to an interpretation scale indicates high, moderate or low concern for ground water contamination by pesticides. RAVE score cards may be obtained by requesting MDA Technical Bulletin 90-01 from:

Montana Department of Agriculture
Agricultural Sciences Division
Helena, MT 59620-0205

Ground water contamination maps of Montana are also available to identify areas that contain soils that are potentially susceptible to contaminant movement (MontGuide MT9107AG, Ground Water Contamination Potential Maps of Montana). The maps can aid in identifying general areas where pesticides may rapidly leach into ground water. Application rates, timing and pesticide selection can then be adjusted accordingly. MontGuide MT9107AG is available through your county agent and color maps for a particular county may be purchased ($1.00 each) from:

Extension Soils
Department of Plant, Soil and Environmental Sciences
334 Leon Johnson Hall
Montana State University
Bozeman, MT 59717-0312

Selection, handling and application of pesticides

The following pest management and pesticide handling practices can reduce the potential for contamination of ground and surface water.

Selection of Pesticides

Insect, weed or disease pests should be accurately identified to select the most effective pesticide. Use a pesticide manual for selection information. When selecting a pesticide, consideration should be given to soil and site characteristics, and pesticide persistence and mobility. A pesticide known to leach should not be used in an area with a shallow water table or on coarse soils.

Some pesticides listed in Table 3 have restricted use due to acute toxicity or high persistence. The threat to non-target species and water contamination may be minimized by following the pesticide label.

Pesticide Handling and Use

Leave buffer zones around sensitive areas

When storing, handling, applying, or disposing of pesticides (including clean-up of equipment after application) consider the location of surface waters, wells and ground water recharge areas. Establishing and maintaining vegetation or leaving an untreated border are two ways to provide a buffer zone between a pesticide application or handling site and a sensitive area. A minimum buffer zone of 100 feet is suggested (Figure 3).

Wellhead protection

Wells are direct pipelines to aquifers. Direct contamination through a wellhead is the most common and greatest threat to ground water. Pesticides enter a well directly from the surface, through openings in the well casing, along the outside wall of the well casing, or through the soil adjacent to the well.

Properly constructed wells prevent ground water contamination (Figure 4). Well casing forms the wall of the well and keeps the borehole open. A non-permeable cement compound or grout should be forced into the space between the borehole and the outside of the well casing to prevent water and contaminants from moving down along the outside of the casing. Seal or cap the top of the well casing about eighteen inches above the ground or at least high enough to prevent the entry of surface water and/or contaminants.

Inspect wells and pumps regularly for leaks and proper sealing. Never dispose of wastes in unused wells. (Wells should always be filled in a way that prevents water movement within the drill hole.) Properly close all abandoned wells. Contact your local office of the Montana Department of Natural Resources and Conservation for licensed well drillers who can properly seal drilled wells. An Extension Service video on wells is in progress which explains the procedure to seal abandoned hand dug wells. (Check with your country agent or call 994-3273 to determine availability.)

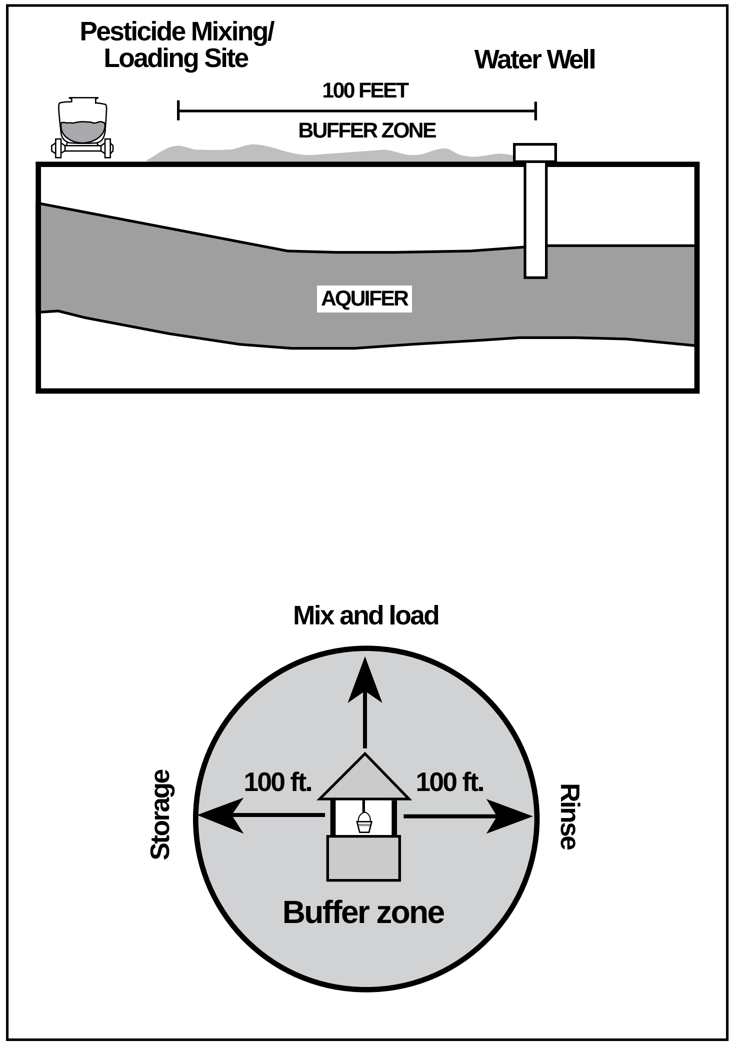

Figure 3. Buffer zones guidelines.

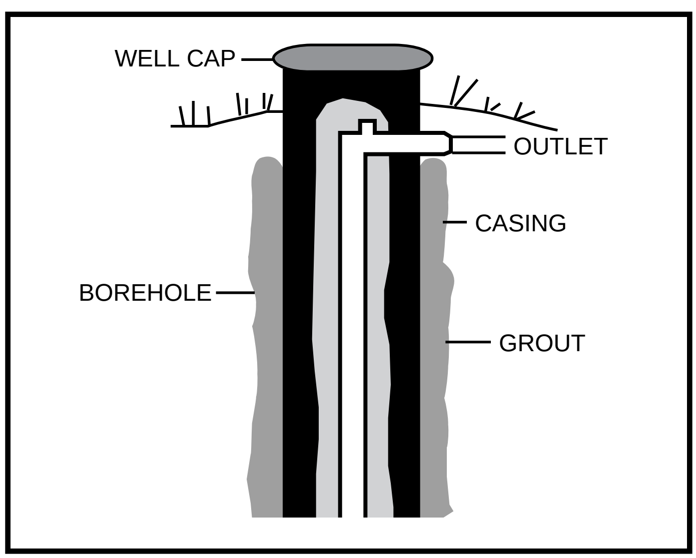

Figure 4. Properly constructed well.

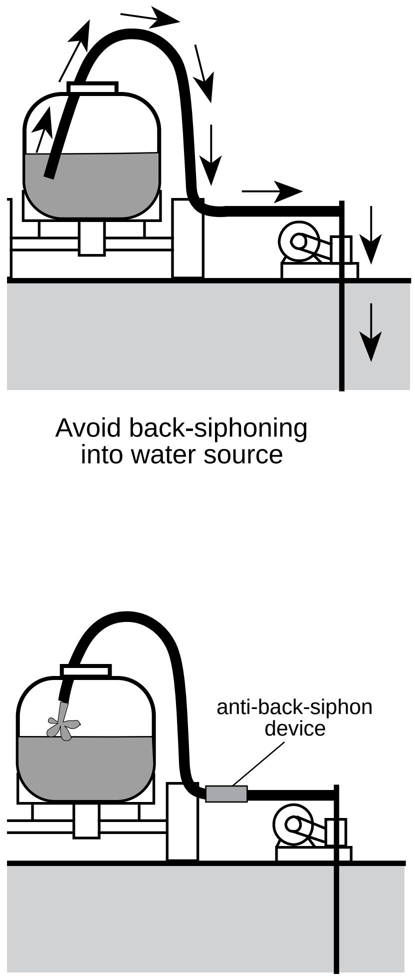

Figure 5. Devices to prevent back-siphoning are essential for mixing sites.

Surface runoff can be intercepted or diverted from the wellhead by grading the soil or building diversion terraces or ditches up-slope from a well. Frequent monitoring of the area around a well will ensure that changes in land use do not increase the risk of contamination. Do not store, handle or use pesticides where they can enter a well or any water source.

Read the pesticide label

Pesticide labels contain instructions on application rates, safety precautions, potential environmental hazards, reentry intervals, grazing restrictions and other pertinent information about safe pesticide use. Review this information carefully before purchase, before mixing and application, before the pesticide is stored and before disposing of the pesticide or container. Some labels offer specific information on preventing ground water contamination.

Protect water during mixing

Accurately measure the proper pesticide concentration and mix only the amount needed. Never exceed label application rates. Wear protective clothing and handle pesticides carefully to avoid accidental spills and personal harm. Take necessary precautions to keep pesticides from reaching the soil, wells or any water source when mixing and loading. Repeated pesticide spills in the same area can exceed the soil's adhesion and degradation capacity and contaminate ground water. If mixing at the same site is advantageous, build a liquid-tight, curbed, concrete surface mixing/containment pad to avoid saturating the soil with pesticide. If mixing and loading near a water source is unavoidable, use as long a hose as possible to separate pesticide operation from the water source. It is preferable to use closed application systems to reduce spill potential while mixing, but this is not practical nor required of private applicators.

Back-siphoning pesticide into the water supply must be prevented. Accidents have happened where the water pump stopped, and the filler hose has siphoned the tank mixture back into wells, ponds, or streams (Figure 5). Precautionary measures can prevent back-siphoning:

- Never leave a spray unit unattended when filling
- Keep the end of the fill hose above the liquid level in the spray tank
- Install and maintain anti-backflow devices (check-valves) on all pumps and water valves and especially on the fill hose

Store pesticides safely

Significant environmental contamination may result if pesticide containers break from rough handling, weathering, corrosion or age. Proper storage of pesticides protects chemical longevity, people and the environment. Carefully plan pesticide storage and mixing areas. Find a location safe from runoff and distant from sensitive areas. Build a secure storage facility and a concrete loading area, with curbing around the perimeter.

Pesticide and container disposal

Dispose of chemicals safely by following all label instructions and restrictions. Several ounces of pesticide in a discarded container continue to be a serious safety and pollution hazard. Careless disposal can cause chemical injury or concentration in the soil which then contaminates water. Triple rinse or pressure rinse pesticide containers immediately after they are emptied and pour the rinsate into the spray tank. Triple-rinsed containers not suitable for recycling or refilling by distributors may be disposed of at designated landfills. Burning empty pesticide containers is illegal in Montana.

Minimize creation of excess spray mix by accurately measuring the needed amount. Excess spray mix and rinsates from equipment cleaning may be sprayed on crops as listed on the label. Rinsing application equipment and spraying rinsates in the field may be facilitated by providing a clean water source at the application site (nurse or saddle tank).

Never dispose of pesticides or pesticide containers near a water source, where there is a shallow aquifer or in abandoned wells.

Transportation of pesticides

An accident while transporting a pesticide product could spill a large amount of concentrated chemicals and pose a substantial water contamination threat. Inspect containers for leaks, tears and punctures before transport. Make sure all labels are legible. Firmly secure containers to prevent movement during transit. Carry cleanup materials including protective clothing, a shovel, absorbent material and empty containers to contain a spill if one should one happen.

In Case of Spills

Be prepared for spills. Since different chemicals require different actions, the "Emergency Response Information Sheets," or "Material Safety Data Sheets" from pesticide manufacturers should be on hand for each pesticide. These provide detailed information about what to do in case of a spill. The containment and cleanup procedures should be known in advance for each of the stored pesticides, and containment and cleanup materials should be on hand.

If a spill does occur, be sure to wear protective clothing and act immediately to clean up the spill:

- Control the spill—place torn or punctured containers into larger empty ones
- Stand overturned containers upright
- Contain the spill—limit chemical spread by using a soil dike or dam of absorbent material
- Add an absorbent to liquids (e.g., cat litter, commercial absorbent), dirt, sawdust)
- Clean up the spill—including contaminated absorbent material
- Decontaminate or neutralize contaminated areas using neutralizing agents referred to in data sheets metioned above
- Clean equipment
- Excavate contaminated soil

If a spill occurs that could be hazardous to people, animals, the water or the environment, call:

Montana Department of Agriculture
Agricultural Sciences Division
Helena, MT 59620
(406) 444-2944

Also, contact the Montana Hazardous Materials Emergency Response System at 1-800-426-9440 or 1-406-444-6911. If the spill presents a hazard to people, or if it may enter surface water, also contact the National Response Center at 1-800-424-8802.

Application of Pesticides

Timing and frequency of application

Timing is based on correct identification, thresholds and control options. Application should be planned to avoid rainfall and irrigation, which dilutes the pesticide and increases contamination potential. Leaching potential is also minimized when the applied pesticide is fully used or when soil conditions promote degradation. Fewer pesticide applications are necessary when they are timed to pest problems, crop growth, irrigation and rainfall.

Dosage rates

Using more product than the label recommends seldom improves pest control, may increase crop injury and is expensive and unlawful. Rough approximations in dosage rates often lead to over- or under-application of the pesticide. The cost of pest control and the potential for the pesticides reaching ground or surface water are increased by over-application of a pesticide. It is a common misconception that a higher application rate will have a greater impact on target organisms. The pesticide label carries application rate information.

Equipment calibration and maintenance

Pesticide application equipment should be accurately calibrated to ensure even pesticide application at intended rates. Inaccurate calibration and excessive application overlap can cause over-application and increased costs. If too much pesticide is applied in one spot, normal degradation processes may be hindered, plant absorption and soil adhesion may be overwhelmed. Check operating manuals for proper calibration methods to achieve desired application rates. Automatic volume regulating devices, which cause spray pressure to vary accordingly with the speed of the application equipment, may help to ensure the proper pesticide application rate. When calibrating, check boom height and pattern overlap to avoid over- or under-application. Check the spray pattern and nozzle flow daily. Recalibrate equipment before each season and with each change in delivery rate or formulation.

Maintain pesticide application equipment regularly. Check for leaks, malfunctions, and worn parts to minimize the potential for spills. Worn parts, especially those that affect pesticide delivery (hoses, valves, gauges, spray nozzles, pumps, screens, etc.) should be replaced or reconditioned immediately.

Construct a site for regular equipment cleaning to eliminate generating hazardous waste. If possible, build a combination mixing/loading/washing containment pad. Rinse water may be re-used if a separate holding tank for each group of pesticides is maintained. Construction plans for mixing and loading facilities are currently being developed by the Montana Department of Agriculture.

Preventing off-target pesticide movement

Particular attention should be given to the prevention of off-target movement of pesticides because of spray drift, vapor movement, or runoff. Be aware of adjacent sensitive sites such as beehives, sloughs, streams, ditches, or ponds where the water table may be close to the surface.

Pesticide particles or vapors move with air currents. Both spray drift and vapor movement reduce pesticide effectiveness to the target organism. Spray drift can be reduced by applying pesticides when air movement is low, increasing droplet or particle size, lowering spray pressure, using water rather than oil as the carrier, using granules rather than dusts or liquid carriers, using wide-angle nozzles to lower spray release height, and using a spray shield. Avoid spraying during temperature inversions. Temperature influences pesticide degradation rate and ease of evaporation or vapor pressure. Drift reduction additives are available for adding to spray tanks when applications are necessary near water sensitive areas.

Vapor movement of pesticide can be best reduced by selecting non-volatile pesticides where feasible. Volatilization and photodecomposition losses of soil-applied pesticides may be reduced by incorporation of these materials into the soil soon after their application. Proper incorporation of a pesticide will improve its performance and dependability and often allow for reduced application rates. However, incorporating a pesticide too deep, especially in soils high in organic matter or clay content, may cause excessive dilution and decreased performance.

Pesticides may also be carried from their point of application in surface water runoff. Loss of pesticides from the soil surface will probably be minor except under circumstances of rapid runoff or blowing without prior mechanical incorporation or incorporation by irrigation or rainfall. Pesticide concentration is highest in the first runoff following treatment and decreases sharply during the growing season. Eroded soil particles can carry pesticide concentrations 1000 times greater than that in transporting runoff water. No-till and/or mulched systems in crop production can reduce erosion and the movement of pesticides in erodible soils, but they may enhance downward leaching of pesticides.

Summary

Pesticide application requires the use of all current technologies and careful consideration of environmental implications (Table 5). One must consider not only the short-term effects of pesticides, but also their residual properties, breakdown products and eventual environmental fate.

During the last ten to fifteen years, there has been a major change in the characteristics of pesticides. Originally, pesticides were non-mobile and had low water solubility and strong soil adhesion; currently they are more water soluble, have low adhesive properties and are more mobile.

Pesticides that are both persistent and mobile in soil have the potential to reach ground water, especially when soil type, temperature, rainfall, recharge, crop type or other factors contribute to their movement. Pesticides can travel both in soil water and while adsorbed to soil particles that move by erosion. The potential for surface transport by runoff is governed by both persistence and mobility properties of pesticides and climate and soil conditions at the site. No single chemical or physical property of a pesticide uniquely determines its potential for transport via runoff.

Cleanup of soils, geologic materials, ground waters and surface waters is an expensive, complicated, time-consuming proposition—often not even possible. Therefore, it is essential to seek ways to optimize pesticide use and increase its effectiveness to protect the health of people and animals and improve and maintain environmental and economic sustainability.

Table 5. Best management practice summaries

- ✔ Provide an optimum environment for a healthy crop through resistant variety selection, planting date and planting depth, residue and nutrient management, and other related agronomic factors. Renovate pasture and forages to provide adequate ground cover.
- ✔ Use crop rotation, crop selection, weed/disease-free seed, resistant varieties, mechanical, cultural, and biological control measures, when viable, to decrease pesticide use and avoid resistance.
- ✔ Integrate conservation tillage practices to decrease off-site pesticide loss with sediment.
- ✔ Use contour farming, filter strips, field borders, cover crops and field windbreaks to decrease sediment losses from wind and water erosion.
- ✔ Use integrated crop and pest management (IPM) strategies which combine chemical control with other pest management practices.
- ✔ Utilize natural predators and parasitoids whenever possible.
- ✔ Scout fields regularly to identify the pest(s), pest location(s), and severity of infestation.
- ✔ Integrate soil characteristics and geology into pesticide management strategies.
- ✔ Select pesticides with the least potential for leaching or runoff.
- ✔ Only trained individuals should apply pesticides.
- ✔ Consider spot applications of pesticides rather than whole field applications. Hand pull small infestations. Band apply pesticides over the crop row rather than the whole field to reduce the total amount applied.
- ✔ Reduce the quantity of pesticides used where appropriate.
- ✔ Read and follow pesticide label directions concerning proper application rate, timing and environmental hazards.
- ✔ Calibrate application equipment accurately to deliver the correct amount of pesticide.
- ✔ Check equipment for leaks and malfunctions before, during and after an application.
- ✔ All field equipment should be cleared of plant materials to avoid spreading weed seeds and diseases.
- ✔ Purchase, measure and mix only the quantity of pesticide that will be used in a single growing season.
- ✔ Use an anti-backsiphoning device when mixing a pesticide. When filling a spray tank, the end of the fill hose should remain above the water level in the tank.
- ✔ Avoid mixing chemicals near springs or wells (both active and abandoned) by using a long hose so that mixing occurs at least 100 feet *from* the water source. Never mix pesticides directly uphill from any water supply. Use surface diversion practices and erosion control measures for additional protection. Rotate the location of mixing and loading sites.
- ✔ Properly dispose of pesticide containers and pesticides.
- ✔ Consider environmental sensitivity (soil type, hydrology, and runoff) when selecting a location for storage and mixing/loading facilities.
- ✔ Triple rinse or power rinse empty containers. Pour the rinsate into the spray tank for use in treating a crop or site specified on the label.
- ✔ Never drain excess pesticide or pesticide mixtures onto the soil or into sewers, drains, septic systems, ditches, streams, ponds or lakes.
- ✔ Store pesticides in a locked building on an impermeable surface away from water sources.
- ✔ Integrate irrigation events and weather into the pesticide application decision by delaying application if heavy or sustained rain or wind is forecast.
- ✔ Plan pesticide use carefully and evaluate all risks. Avoid pesticide application when conditions are likely to promote leaching.
- ✔ Follow requirements of specific farm management plans.

Pesticide testing

Few comprehensive well testing studies address or test for pesticide contamination in well water, mainly because of the expense and difficulty in pinpointing the pesticide contamination source. Testing a private drinking water supply for pesticides is expensive ($100 per pesticide “family” per sample) and usually is not necessary unless a spill or back-siphoning accident has occurred near the well. According to the well testing program at the MSU Extension Service, testing for coliform bacteria and nitrates is usually a good place to start. If these two contaminants are not present in your water, pesticides are not likely to be present either, although the possibility still exists.

There are cheaper ways to test for pesticides than going to the state lab, if small sacrifices in reliability are acceptble. National Testing Laboratories of Cleveland, Ohio, offer qualitative water analysis on up to 83 contaminants for less than $100. Some contaminants this lab can test for include pesticides, metals, PCBs (pentachlorobenzene), solvents and bacteria. After receipt of a water sample, they will send a complete report of their findings within five days. For more information, contact the National Testing Laboratories at 800-458-3330.

Getting help

The Environmental Protection Agency (EPA) has set up a Safe Drinking Water Hotline. The number is 800-426-4791, and it is answered between 8:30 a.m. and 4:30 p.m. Eastern time. This number was established to help states, the regulatory community, and the public understand the EPA’s regulations under the Safe Drinking Water Act. The staff can answer questions about various drinking water standards and contaminants.

Regional professionals also available for help and assistance with pesticides and water resource protection at the Montana State University Extension Service, the Agricultural Sciences Division of the Montana Department of Agriculture, the U.S. EPA., the State Department of Natural Resources and Conservation, and the U.S. Soil Conservation Service.

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